Surge Testing:
Don’t Kid Yourself, Don’t Kill Yourself

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Significance:
Part 5 – Monitoring instruments, laboratory measurements, and test methods

Progress report to the EMC community on the development of what became IEEE Std C62.45 from the point of view of a trade magazine.
Explains the need for careful planning of a test program, differences between testing for immunity versus vulnerability, the need to consider powered testing, and appropriate methods for coupling the surge into the test circuit. Lists other practical aspects of surge testing, last but not least the mandatory safety review of the tests procedures.

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Increasing awareness of the sensitivity of electronics to surge effects has led to a proliferation of surge suppressors on the market. Confronted with a difficult choice, some users are evaluating the performance of these devices by surge testing. However, the techniques involved in these tests are different from typical EMC testing because of the single-shot nature of the event and because of the potential personnel hazards involved in surge testing. This article presents a brief overview of surge testing, focusing on the unique techniques involved in performing valid tests under safe conditions.

In the old days of electromechanical devices, surge testing was an alternative to hi-pot testing, aimed at demonstrating the dielectric strength of equipment. Today, the emphasis is on demonstrating the immunity of electronic systems against upset or damage by surges occurring on power or data line interfaces, or evaluating the effectiveness of surge suppressors. The traditional tests were performed in high-voltage laboratories by specialists, but the new tests can be performed by anyone with a benchtop commercial surge generator and suitable oscilloscope. This welcome simplification, however, is not without dangers: the danger of overlooking technical subtleties (don't kid yourself) and real hazards (don't kill yourself).

The Surge Protective Devices Committee of the IEEE has completed a new document, "Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits," ANSI/IEEE C62.45-1987, which addresses many of these concerns.* The major concepts can only be summarized here; practitioners and planners of surge testing are urged to consult the IEEE guide. These major concepts (10 commandments?) are the following:

1. Plan ahead!
2. Differentiate between testing for susceptibility and testing for vulnerability.
3. Consider the need for applying the surge superimposed on the ac power.
4. Provide for realistic **combined**, not separate, voltage and current tests.
5. Provide adequate coupling of the surge into the test power line.
6. Isolate the room power supply from the surge with a back-filter.
7. Consider the polarity and phase relationship of surge timing.
8. Consider the implications of repetitive application of single surges.
9. Monitor the surge with suitable instrumentation.
10. Last in the list, but first when operating, be safe.

*The figures are reprinted from ANSI/IEEE C62.45-1987, Copyright 1987 by the Institute of Electrical and Electronics Engineers, Inc., by permission of the IEEE Standards Department. The concepts outlined in this article reflect that document. The contributions of the IEEE working group members to the development of the "Guide," and thus this article, are gratefully acknowledged.

1. Plan Ahead.

There is more to surge testing than connecting the test article to the output terminals of a zapper and watching for smoke. Every aspect of testing must be considered and coordinated. Figure 1 provides a graphic illustration of the interactions between goals, outcomes, equipment and procedures.

2. Differentiate between testing for vulnerability and testing for susceptibility.

Surge protective devices are often applied only for avoiding damage; however, they can also serve to prevent upset in the operation of the equipment. Therefore, the subject of surge testing must recognize both outcomes of a surge: upset (susceptibility) and damage (vulnerability). This differentiation must be defined **before**

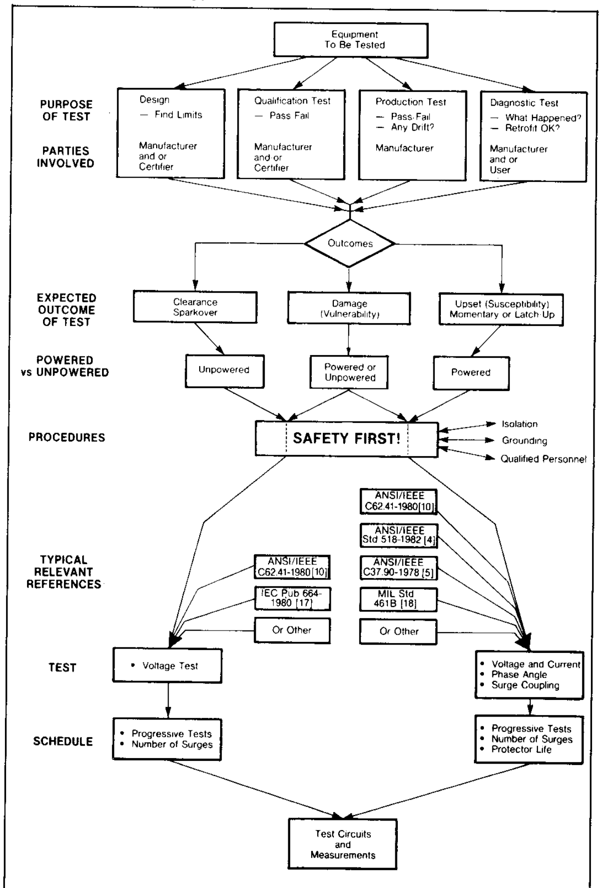

Fig 1
Guiding Considerations for Surge Testing

Figure 1—Considerations Involved in Planning a Surge Test

the tests are conducted so that the parties involved can agree on appropriate pass/fail criteria.

3. Consider the need for applying the surge superimposed to the ac power.

Test surges can be applied to the equipment under test (EUT) in two ways: (1) with normal operating power disconnected from the EUT (unpowered testing), and (2) with normal operating power applied to the EUT (powered testing). The intended purpose of the test determines whether one approach is sufficient or whether both are required.

Unpowered testing may appear sufficient in situations for which the test outcome does not depend on evaluation of EUT performance during the surge. For instance, clearance flashover of an electromechanical device might be the failure criterion; in that case, there usually should be no need to power the EUT. However, unpowered testing does not represent actual service conditions.

Powered testing is necessary under two circumstances: (1) when the test outcome depends on evaluation of EUT functional performance during the surge, and (2) when determination of EUT vulnerability can involve power-follow (which may also depend in part on the phase angle at which the surge is applied with respect to the line voltage wave). Thus, a test for susceptibility implies normal equipment functioning prior to the surge; therefore, it can only be checked in the powered mode. From the standpoint of good practice, it is best to perform laboratory tests in a manner that most closely simulates the actual service environment.

4. Provide for realistic combined, not separate, voltage and current tests.

The nature of the EUT will affect its response to an applied test surge. A high-impedance EUT, such as a winding, a clearance or a semiconductor in the blocking mode, will be stressed by a voltage surge. In these cases, the energy associated with the surge is not significant. A low-impedance EUT, such as a circuit containing filter capacitors or surge-diverting protective devices, will be stressed by a current surge; the energy deposited in the components becomes a significant factor in this type of surge occurrence.

Therefore, the wave shapes for both voltage and current tests therefore must be considered in specifying a test procedure. Thus, the generator should be capable of a dual role: (1) For an expected voltage test, a sudden impedance drop must be accompanied by a specified surge current (amplitude and wave form) to ensure both marking the defect and initiating power-follow current. (2) For an expected current test, the voltages involved must be held between a low and a high limit to initiate current by a sparkover-type device while not exceeding an appropriate upper limit. While the need for providing these two conditions may not always be apparent, ignoring them can lead to meaningless testing. An example is if a generator of high internal impedance or low stored energy is applied for performing a voltage test on an EUT which has relatively low input impedance.

5. Provide adequate coupling of the surge into the EUT power supply.

Coupling the surge to an unpowered EUT is a simple matter: just connect the EUT to the terminals of the surge generator. In the case of a powered test, however, the coupling becomes a complex matter. This complexity is the result of the need to apply the surge to the line supplying the EUT, maintaining the specified waveform while transferring the necessary energy to the EUT. Simple two-terminal devices can be subjected to the surge in a simple configuration; multi-terminal devices require careful attention to specifying which terminals are surged with respect to which others. This concern is often described as testing for common mode or testing for normal mode. Because a detailed discussion would take a whole article by itself, this concern is only mentioned here.

6. Isolate the room power supply from the surge with a back-filter.

A further complication introduced by powered testing is the need to isolate the room power supply from the test circuit with a back-filter. There are two good reasons to do this: (1) The purpose of the test is to subject the EUT, not the whole laboratory, to the test surge. (2) The relatively low impedance of the room power supply would load down the surge generator and prevent it from delivering the desired amplitude for the test surge. The design of this back-filter, however, is not trivial because the filter must allow enough line current to supply the normal load current to the EUT but cause a minimum of interaction with the pulse-shaping network of the surge generator.

7. Consider the polarity and phase relationship of surge timing.

Depending on the nature of the EUT, the polarity of the test surge may have an effect on the EUT response. A more subtle effect may involve the timing of the test surge with respect to the power-frequency sine wave: the effect of a surge on a power semiconductor may be different if the device is in reverse bias or is conducting at the time the surge is applied. If the behavior of the EUT involves a sparkover—intentional or accidental—the timing of the surge affects the power-frequency current initiated by the sparkover.

8. Consider the implications of repetitive application of single surges.

The test surges are single events, but they will be applied many times to the EUT for a number of reasons: (1) Prudent practice is to start a test with a low-severity test and increase the severity level in steps to determine the threshold of interference or damage. One important aspect of this procedure is the risk of overlooking blind spots in the performance of the EUT if the test surge were applied only at the maximum severity level. (2) The need for bipolar testing and exploring the effects of phase relationship of the surge timing quickly multiplies the number of shots required to cover all the possible conditions. (3) Worse yet, should the EUT response involve timing of the surge with the internal clock and transitions of the EUT logic, then we may be considering **thousands** of single pulse applications! Thus, the cumulative effects of all these surges on the EUT (such as temperature rise at fast repetition rate, long-term degradation even at slow repetition rate) must be considered. Some average power limitation must be defined, as well as a waiting time between surge applications.

9. Monitor the surge with suitable instrumentation.

The need to monitor the input surge is axiomatic for verifying the characteristics of the applied surge, both open-circuit and as modified by the load. For simple failure modes of isolated components, such as insulation breakdown or permanent semiconductor damage, monitoring the applied surge reveals a failure as the applied voltage wave is chopped. Checking a complex EUT for susceptibility requires more extensive instrumentation to detect a misoperation. (That instrumentation itself must be immune to the disturbances created in the area by the test surge.)

Monitoring within the EUT may also be required to understand the failure mechanism under the surge, or to control one or more critical voltages within the EUT. It may also be required to check the amount of surge remnant or surge let-

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through reaching specific critical components.

10. Be safe!

There are two major considerations in the quest for safety during the test procedure. The first, fairly obvious, is that the voltage and energy levels applied to the EUT are generally hazardous and, therefore, deserve respect. That respect is best enforced by providing a barrier around the test circuit, including all of the EUT and leads that are not disconnected during the test (see Fig. 2). The second, less obvious consideration is that under fault conditions (which are not always predictable) high voltages can appear at unexpected points during a flashover or between points considered to be "ground potential." In surge testing, there is seldom anything that can be considered "ground" within the EUT. All of the monitoring measurements must be accomplished by differential connection of the probes (see Fig. 3). This type of connection enables use of a safely grounded oscilloscope with high-voltage probes that have no ground leads attached to the EUT, while the chassis of the oscilloscope is safely grounded by the grounding conductor of its ac power cord. Note that the grounding pigtails of the probes are **not** connected to the "ground" of the EUT. The practice of a floating scope should be studiously avoided in surge testing. This requirement, however, introduces concern about the common-mode rejection ratio of the instrumentation, a source of errors if not properly addressed. This last concern provides a good example of the duality of surge testing implied in the title of this article: safety must not be compromised, even if mandatory safety procedures could lead to more difficult measurements. Using an unsafe test method in the belief that it is the only one yielding valid results is not acceptable. The perceptive, prudent and proficient operator will keep both imperatives in mind and emerge alive from the tests, with reliable results.

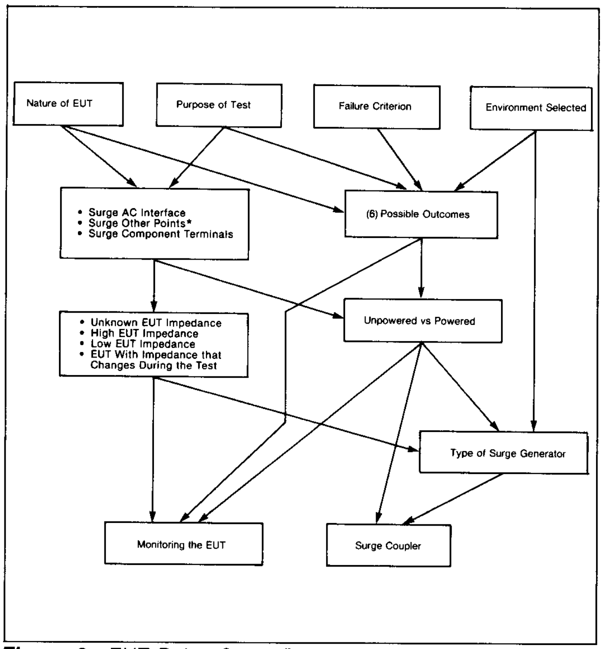
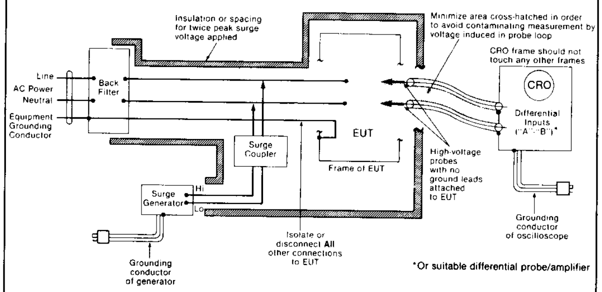


Figure 2—EUT Being Surge Tested, Showing Required Interfaces, Filters, and Reterminations



NOTE: The bonding of probe shields to each other at the measuring end of the probes (they are both connected to the oscilloscope chassis at the other end) has been advocated by some workers, while discouraged by others. The benefit of either method might be dependent upon the particulars of the situation. A check for noise background (both probes connected to the same point) will provide the basis for a selection tailored to the particular situation.

Figure 3—Monitoring within Surged Equipment with Voltage Probes in Differential Connection